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ON HEREDITY AND REJUVENATION.[1]

BY CHARLES SEDGWICK MINOT.[2]

The subject of this article is presented under the following sections:

I. The Formative Force of Organisms.

II. The Conception of Death.

III. A Comparison of Larva and Embryo.

IV. Concluding Remarks.

The first section is not new, but a reproduction without change, of an article published in *Science*, July 3d, 1885. As this article has not become generally known, and yet is an essential link in the chain of reasoning, I venture to repeat it- Though written in 1885, I consider that to-day it is still sufficient to disprove Weismann's theory of germ plasm. Weismann has not considered this article, otherwise, from my point of view, he could not have maintained his theory.

[1] This article is translated from one which appeared in the Biologisches Centralblatt, Vol. XV, Page 571, August 1st, 1895. A few trifling changes have been made in the text. An abstract of the article was read before the American Association for the Advancement of Science, at its recent Springfield meeting.

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The views which I then defended have been recently brought forward in almost parallel form, and without essential additions, by O. Hertwig (*Zeit-und Streitfragen der Biologie*, I, Heft, D. 32–53) as arguments against the views of Weismann.

The second section is also directed against Weismann, for it attempts to replace his conception of death by one more exact.

The third section is intended to make the significance of rejuvenation clear, and at the same time, by a comparison of larvæ and embryos, to demonstrate a law of heredity which has not been hitherto recognized.

The Formative Force of Organisms.

The assertion is safe, that the majority of biologists incline at present to explain the forming of an organism out of its germ upon mechanical principles. The prevalent conception is that the forces of the ovum are so disposed that the evolution of the adult organism is the mechanical result of the predetermined interplay of those forces. The object of the present article is to point out that this conception is inadequate, and must be at least supplemented, if not replaced, by another view, namely, that the formative force is a generally diffused tendency, so that all parts inherently tend to complete by their own growth and modification the whole organism—a fact which finds a legitimate hypothetical expression in Darwin's Doctrine of pangenesis. The nature of the view here advanced will become clearer upon consideration of the evidence upon which it is based, and which is adduced below. The evidence that the formative force is diffused through all parts falls under three heads: 1. The process of regeneration in unicellular and multicellular bionts; 2. The phenomena of of the duplication of parts; 3. All forms of organic reproduction. Let us briefly consider these categories.

1. *Regeneration.*—All living organisms have, to a greater or less degree, the ability to repair injuries; indeed, we must regard the power of regeneration as coextensive with life, but

the capacity varies enormously in the different species. In man the power is very small, though more extensive than is generally realized. Among Annelids are species, the individuals of which may be divided in two, and each piece can regenerate all that is needed to render it a complete worm. We sometimes see a small fragment of a plant, a single switch of a willow, for instance, regenerate an entire tree, roots, trunk, branches, leaves, flowers, and all. In the last instance a few cells possess a latent formative force, which we recognize by its effects, but cannot explain. We perceive, therefore, that each individual has, as it were, a scheme or plan of its organization to which it strives to conform. As long as it actually does so, the cells perform their routine functions; but when an injury destroys or removes some portion, then the remaining cells strive to conform again to the complete scheme, and to add the missing fragment. The act of regeneration of lost parts strikes the imagination almost as an intelligent pursuit by the tissues of an ideal purpose.

Our knowledge of the regeneration power has recently received important extensions through the noteworthy experiments of Nussbaum[3] and Gruber,[4] who have demonstrated, independently, the possibility of dividing unicellular animals so that each piece will regenerate the missing parts. In this manner the number of individuals can be artifically multiplied. For example: Nussbaum divided a well-isolated Oxytricha into two equal parts, either transversely or longitudinally, and found that the edges of the cut became soon surrounded with new cilia. Although some of the substance of the body, or even a nucleus, was lost through the operation yet, by the following day, the two parts converted themselves into complete animals with four nuclei and nucleoli (*Nebenkerne*) and the characteristic ciliary apparatus. "The head piece has formed a new hind end; the right half, a new left half." The

[3] M. Nussbaum, *Ueber spontane und kunstliche Zellteilung*, Sitzungsb. d. neiderrh. Ges. f. Nat. u. Heilkunde, Bonn, 15, Dez., 1884.

[4] A. Gruber, *Ueber kunstliche Teilung bei Infusorien*, Biol. Centralblatt, Bd. IV, No. 23, 717--722.

newformed duplicate Infusoria multiplied subsequently by spontaneous division. From one Oxytrachia cut in two, Nussbaum succeeded in raising ten normal animalcules, which subsequently all encysted. After an unequal division, the parts are both still capable of regeneration, but parts without a nucleus did not survive, which suggests that the formative energy is in some way bound up with the nucleus. But nucleate pieces may break down. Thus, all attempts at artificial multiplication of the multinucleate Opalina failed, although the division of Actinosphærium had been successfully made by Eichhorn as long ago as in the last century. Pelomyxa palustris has been successfully divided by Greef, and Myastrum radians by Haeckel.

Gruber (*l. c.*, p. 718) describes his experiments with Stentor: "If one divides a Stentor transversely through the middle, and isolates the two parts, one finds on the cut surface of the hind part, after about twelve hours, a complete peristomial field with the large cilia and buccal spiral newly formed. On the other hand, the piece on which the old mouth is situated has elongated itself backwards, and attached itself in the manner peculiar to these Infusoria. If one has made a longitudinal section, so that the peristom is cut in two, then the peristoms both complete themselves and the lateral wounds heal over. I have repeatedly separated, by transection, pieces considerably less than half of the original Stentor, and these have also regenerated themselves to complete animals." Gruber, too, observed that artificially divided Infusoria were capable of subsequent spontaneous multiplication. If the section is not very deep, there may arise double monsters; but here, just as in spontaneous divisions, as long as there remains an organic connecting band, the two parts act as one individual, showing that the nervous actions are not restricted to determined paths. Gruber also adds that two divided pieces may be reunited if brought together quickly enough. The observation thus briefly announced is of such extreme interest and importance that the publication of the full details of the experiment will be eagerly awaited. Gruber adds that at present we can-

not go much beyond the proof of existence, to a high degree, of the regenerative capacity in unicellular organisms, He also makes the significant observation that in the Protozoa, we have to do foremost with changes of function ; in the Metazoa, with growth also.

2. *Duplication of parts.*—In these anomalies we find an organ which, although an extra member, yet still conforms to the type of the species. For example: a frog is found with three posterior limbs ; dissection proves the third leg to agree anatomically with the typical organization of the frog's hind leg. In determining the importance to be attributed to this evidence, it should be remembered, on the one hand, that these instances are by no means unusual ; on the other, that the agreement with the normal structure is not uniform.

3. *Asexual reproduction.*—When a species multiplies by fission of any kind, we must assume that each part, after division, possesses the formative tendency, since we see it build up what is necessary so complete the typical organization of the individual. Again: a bud of a hydroid or polyzoon, although comprising only a small part of the body, is equally endowed with this uncomprehended faculty. In pseudova we reach the extreme limit; in aphis, for example, the parent gives off a single cell, the capacity of which, to produce a perfect and complicated individual, fully equals the like capacity of a hydroid bud or of half a worm.

The evidence forces us to the conclusion that the formative force or cause is not merely the original disposition of the forces and substances of the ovum, but that *to each portion of the organism is given: 1. The pattern of the whole organism; 2. The partial or complete power to reproduce the pattern.* The italicized formula is, of course, a very crude scientific statement, but it is the best which has occurred to me. The formative force, then, is a diffused tendency. The very vagueness of the expression serves to emphasize our ignorance concerning the real nature of the force. In this connection, I venture to insist upon the fact that we know little or nothing concerning any of the fundamental properties of life, because I think the

lesson of our ignorance has not been learned by biologists. We encounter, not infrequently, the assertion that life is nothing but a series of physical phenomena ; or, on the other hand, what is less fashionable science just now, that life is due to a special vital force. Such assertions are thoroughly unscientific ; most of them are entirely, the remainder nearly worthless. Of what seems to me the prerequisites to be fulfilled before a general theory of life is advanced, I have written elsewhere.[5]

II. Conception of Death.

My thesis reads : There are two forms of death. These are *first*, the death of the single cells ; *second*, the death of multicellular organisms. Death in the one case is not homologous with death in the other.

Weismann assumed the complete homology of the two forms of death. Without this assumption, his hypothesis of the immortality of unicellular organisms falls to the ground and with it falls the entire superstructure of his speculations upon germ plasm. Oscar Hertwig (*Zeit und Streitfragen, Heft* 1) has already expounded, very clearly, the dependence of the theory of germ plasm upon the hypothesis of unicellular immortality ; it would, therefore, be superfluous to discuss it here.

The conception of the biological problem of death, to which I still hold, was formed several years before Weismann's first publication, which appeared in 1882, with the title, "*Ueber die Dauer des Lebens.*" He has further defended his view in his article, "*Ueber Leben und Tod*" (1884), and has steadfastly adhered to it since. In the years 1877–1879 I published my theoretical interpretation of the problem.[6] This interpretation became the starting point of elaborate special investigations, by which I endeavored to advance the solution of the problem and, in fact, observation and experiment have confirmed the

[5] C. S. Minot, *On the conditions to be filled by a theory of life,* Proc. Amer. Assoc. Adv. Sc., XXVIII, 411.

[6] Proc. Boston Soc. Nat. Hist., XIX, 167 ; XX, 190.

original thesis.[7] Moreover, in an especial short article I have directed attention to the fact that Weismann has not considered the essential issue of the problem. The difficulties pointed out still remain, and, according to my conviction, cannot be removed. Weismann passes these difficulties by and carries out his speculations without first securing a basis for them. His method is illustrated by the following quotation: "I have, perhaps, not to regret that I cannot here discuss the article referred to (Minot's Article in *Science*, Vol. IV, p. 398); nevertheless, almost all objections which are there made to my views are answered in the present paper." (Weismann, Zur Frage nach der Unsterblichkeit der Einzelligen, Biol. Centralbl., IV, 690, Nachschrift). I have studied the paper with conscientious care and cannot admit that the objections have been answered. On the contrary, I maintain now, as formerly, the judgment: "He misses the real problem." For this reason I hold it to be unnecessary to discuss the details of Weisman's exposition, because—if I am right—he has not considered the actual problem of death at all. "He misses the real problem." The following reasoning leads to this decision: Protozoa and Metazoa consist of successive generations of cells; in the former the cells separate; in the latter they remain united; the death of a Protozoa is the annihilation of a cell, but the death of a Metazoon is the dissolution of the union of cells. Such a dissolution is the result of time, that is to say, of the period necessary to the natural duration of life, and we call it, therefore, "*natural death.*" Moreover, we know that natural death is brought about by gradual changes in the cells until, at last, certain cells, which are essential to the preservation of the whole, cease their functions. Death, therefore, is a consequence of changes which progress slowly through successive generations of cells. These changes cause senescence, the end of which is given by death. If we wish to know whether death, in the sense of natural death, properly so called, occurs in Protozoa or not, we must first pos-

[7] Journal of Physiology, XII, and Proc. A. A. A. S., XXXIX, (1890).

sess some mark or sign, by which we can determine the occurrence or absence of senescence in unicellular organisms.

Around this point the whole discussion revolves. Certainly a simpler and more certain conclusion could hardly be drawn than that the death of a Metazoon is not identical, *i. e.*, homologous with the death of a single cell. Weismann tacitly assumed precisely this homology, and bases his whole argument on it. In all his writings upon this subject, he regards the death of a Protozoon as immediately comparable with the death of a Metazoon. If we seek from Weismann for the foundation of this view we shall have only our labor for our pains. Starting from this view Weismann comes to the strictly logical conclusion that the Protozoa are immortal. This is a paradox! In fact, if one compares death in the two cases, from Weismann's standpoint, then we must assume a difference in the causes of death, and conclude that the cause in the case of the Protozoa is external only, while in the Metazoa it is internal only, for, of course, we may leave out of account the accidental deaths of Metazoa. If we approach the problem from this side, we encounter the following principal question: Does death from inner causes occur in Protozoa? Weismann gives a negative answer to this question, with his assertion that unicellular organisms are immortal. The assertion remains, but the proof of the assertion is lacking. In order to justify the assertion, it must be demonstrated that there does not occur in Protozoa a true senescence, showing itself gradually through successive generations of cells. Has Weismann furnished this demonstration? Certainly not. He has, strictly speaking, not discussed the subject. It is clear that we must first determine whether natural death from senesence occurs in Protozoa or not, before we can pass to a scientific discussion of the asserted immortality of unicellular beings. The problem cannot be otherwise apprehended. Weismann has not thus conceived it, therefore the judgment stands against him: *he misses the real problem.*

Senesence has been hitherto little investigated; for many years I have been studying it experimentally and have tried

to determine its exact course. My paper, "Senesence and Rejuvenation," affords evidence of new facts proven by these experiments. I believe I have thus won the right to oppose my view to the pure speculations of Weismann.

(*To be continued.*)

LOST CHARACTERISTICS.

BY ALPHEUS HYATT.

Dr. Minot having noticed, in the translation of his article "On Heredity and Rejuvenation," an accidental omission of quotation of work done by paleontologists on the loss of characteristics in the development of animals, has most courteously asked me to follow his essay by an article dealing with this question. I gladly avail myself of this opportunity on account of the advantages offered where similar subjects can be consecutively treated from different points of view, and because Dr. Minot's article, on account of his great and deserved reputation in embryology, will reach the students of existing biological phenomena, and perhaps induce some of them to read a connected publication.

The loss of characteristics is not so readily observed by a student of the biology of existing animals or neobiologist, as by the paleobiologist or student of fossils, because the latter necessarily deals with series of forms often persisting through long periods of time, and is led, especially if he follow more recent methods of research, to study these in great detail. The observer of these remains is not, as is falsely imagined, limited to fragments, but can and does work out of the hard matrix the external skeletons or shells even of embryos, and can, in the corals, brachiopoda, mollusca, echinodermata and even in protozoa, follow the entire life history of these parts in the individual. He has also the further advantage of availing himself of the knowledge amassed by the neobiologist and neoembryologist, the works of Cope, Beecher, Schuchert, Gurley,